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UNITED STATES
DEPARTMENT OF THE INTERIOR
HAROLD L. ICKES, SECRETARY

BUREAU OF MINES
JOHN W. FINCH, DIRECTOR

INFORMATION CIRCULAR

SOME PERTINENT INFORMATION ABOUT MINE GASES

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INFORMATION CIRCULAR

UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

SOME PERTINENT INFORMATION ABOUT MINE GASES[1]

The air of mines is likely to be contaminated by gases under normal operating conditions, as well as under abnormal conditions that may arise during mine fires and after explosions. The brief outline of the sources, properties, physiological effects, and methods of detection of these gases presented in this circular may be of value to the mining industry as a ready reference on gas hazards and methods of avoiding them.

The material for this paper was taken partly from a chart on mine gases issued by the Bureau of Mines in 1918 (and now out of print) and partly from various other sources but chiefly from published and unpublished data accumulated during the past several years in the field and laboratory work of the Bureau of Mines. The revised compilation was made originally by H. H. Schrenk and supplementary material was supplied by S. J. Davenport and D. Harrington.

SOURCES AND PROPERTIES OF MINE GASES

Chemical and Physical Properties of Gases Most Likely to be Found in Mines[1]

Name	Chemical formula	Molecular weight	Specific gravity (air = 1)	Relative solubility in water at 68° F. (air = 1)	Weight of gas, lb. per cu. ft., 60° F. 30 in. Hg pressure	Explosion hazard	Warning properties, odor or irritation
Air	--	[2]28.97	1.0000	1	0.07655	None	None
Oxygen	O_2	32.00	1.1053	1.66	.08461	None	None
Nitrogen	N_2	28.02	.9674	.824	.07405	None	None
Carbon dioxide	CO_2	44.00	1.5282	46.95	.1170	None	None
Carbon monoxide	CO	28.00	.9672	1.24	.07404	Explosive	None
Hydrogen	H_2	2.016	.06959	.97	.005327	do.	None
Methane	CH_4	16.03	.5543	1.77	.04243	do.	None
Ethane	C_2H_6	30.05	1.0488	2.52	.08029	do.	None
Acetylene	C_2H_2	26.02	.9107	55.08	.06971	do.	Odor
Sulphur dioxide	SO_2	64.06	2.2638	2105.34	.17332	None	Odor and irritation.
Hydrogen sulphide	H_2S	34.08	1.1898	142.88	.09109	Explosive	Odor (in the smaller concentrations).
Nitrogen peroxide	NO_2	46.01	—	—	—	None	Odor and irritation.

[1] In a relatively few mines, petroleum vapors with gasoline or kerosene odors are found due to "oil seeps" from the underlying or overlying rock stratas.
[2] Calculated from composition.

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[1] The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Information Circular 6983."

Atmospheric Air

Pure dry air is a mixture of gases containing 20.93 percent oxygen, 0.03 percent carbon dioxide, and 79.04 percent nitrogen by volume. The nitrogen contains about 1.0 percent of inert gases usually termed "noble" gases. Argon is the principal constituent of the "noble" gases which include neon, helium, krypton, and xenon. Ordinary atmospheric air almost always contains water vapor (moisture, humidity) and particulate matter (dust). The percentage by volume of the various constituents is constant even at a height of 70,000 feet. However, owing to the ease with which gases can be compressed, the pressure of the air itself (14.7 pounds per square inch at sea level) is sufficient to compress it. The weight of air is greater at sea level than at higher levels and gradually becomes less as the height increases. At a height of 17,000 feet the density of air is only half the density at sea level.

Oxygen

Oxygen is the most essential constituent of air, and one can live only a few minutes in its absence. It is also essential for combustion. Oxygen has a marked affinity for many substances, that is, it enters into combination with them, and the normal oxygen content of air (20.93 percent by volume) may be reduced to zero. The depletion or replacement of oxygen in mines is caused by (1) sorption on coal or rock strata; (2) consumption by workmen, open lights, and decay of mine timber; (3) combustion of gas or coal as in mine fires and explosions; (4) combination with pyrite; and (5) dilution of the mine air owing to inrushes of methane, nitrogen, or carbon dioxide from the strata.

Nitrogen

Nitrogen is an inert gas found in atmospheric air. Normally the nitrogen content of air is 79.04 percent by volume (including noble gases). It is usually higher than this in mine air owing to the removal of oxygen (see Oxygen). Atmospheres, having a high nitrogen content may mix with normal air, thereby increasing the nitrogen content of the normal air. The significant physiological effect of nitrogen results from its displacement of oxygen in the air; when such air is inhaled anoxia (oxygen want) results.

Carbon Dioxide

Carbon dioxide is a normal constituent of air and is the product of complete combustion of carbonaceous material. Usually the carbon dioxide content of mine air is higher than the normal amount (0.03 percent by volume) in air. The excess comes from (1) oxidation of coal and other carbonaceous matter; (2) burning of lamps; (3) combustion of blasting powder; (4) burning of gas or coal dust as in mine explosions; (5) exhaust gases from internal combustion engines; (6) breath of workmen and animals; and (7) escape from pores of the coal and rock strata.

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Carbon Monoxide

Carbon monoxide (white damp) is not a normal constituent of air. It is produced in mines by (1) incomplete combustion of carbonaceous matter such as coal, gas, or wood as in mine fires, explosions, or spontaneous heating of coal; (2) reduction of carbon dioxide with red-hot carbon as when the flame of a blast or a gas explosion is projected into an atmosphere filled with fine coal dust; (3) combustion of explosives in blasting; and (4) exhaust gases from internal combustion engines. Carbon monoxide is the chief poisonous gas contaminating mine air, but so far as is known it has not been found in mines in explosive amounts.

Hydrogen

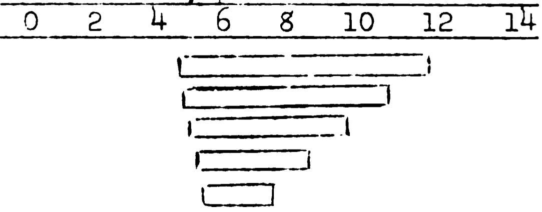
Hydrogen is formed in mines in much the same way as carbon monoxide - by incomplete combustion of gas or coal during mine explosions and mine fires and by firing blasting explosives. It may also be formed when water comes in contact with incandescent coal or rock strata as in extinguishing mine fires. Hydrogen occasionally has been found mixed with methane coming through the strata into mine workings. Although hydrogen is explosive in air it is seldom found in mines in explosive percentages.

Methane

Methane (fire damp or "gas") is given off constantly in many coal mines, and under some conditions small quantities may be found in almost any coal mine; owing to its inflammable and explosive properties when mixed with air in certain proportions, it is responsible either directly or indirectly for most mine explosions and for many mine fires. It escapes from pores and openings in the coal, especially from freshly exposed coal. It may issue from the floor or roof, or from both under some conditions; and it may come from the entire face or from a crack or crevice in the form of a strong flow as a blower or feeder. It is also found in some iron-ore mines, salt mines, and other mines and is encountered frequently in digging tunnels or sinking caissons and shafts. Methane occurs naturally, but it may be formed by distillation of coal during mine fires and dust explosions; it is also produced by the decay of vegetable matter such as mine timber under water and has caused serious explosions during dewatering not only of coal but also of metal and nonmetallic mineral mines. Methane is readily ignited by open flames or electric arcs, but is difficult to ignite by a frictioned spark, although some other gases are readily ignited by them.

Effect of Increasing Carbon Dioxide Content on the Explosibility of Methane-air Mixtures

CO_2, percent	Explosive limits of methane, percent	
	Lower	Upper
0	5.24	1/14.0
5	5.4	12.7
10	5.6	11.4
15	5.8	10.2
20	6.0	9.0
2/25		

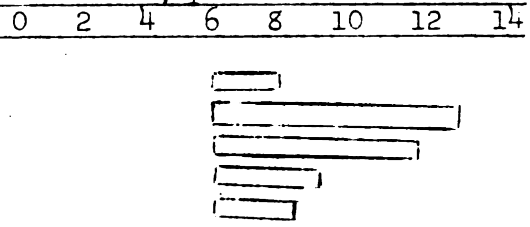


1/ Limits vary somewhat depending upon experimental conditions.
2/ Nonexplosive.

Carbon dioxide in concentrations found in coal mines has essentially no effect on the explosive limits of methane. The carbon dioxide content of the gases behind coal-mine fire seals is occasionally as much as 10 percent but is usually under 5 percent. The carbon dioxide content of working places in coal mines rarely exceeds 2 percent under normal conditions.

Effect of Reducing the Oxygen Content of Methane-air Mixtures on the Explosibility of Methane

Oxygen, percent	Explosive limits of methane, percent	
	Lower	Upper
19.0	1/5.24	
18.0	5.24	14.00
17.0	5.28	12.75
15.0	5.38	9.80
14.0	5.50	8.70
2/12.0		



1/ Limits vary somewhat depending upon experimental conditions.
2/ Nonexplosive.

Reducing the oxygen content of methane-air mixtures lowers the upper limit of explosibility and narrows the range but has no significant effect on the lower limit. When the oxygen is 12 percent or less, methane-air mixtures are not explosive.

In mine-fire extinction by sealing it is important to keep the oxygen content as far below 12 percent as possible.

Ethane and Natural Gas

"Natural gas" is a term applied to a mixture of gaseous hydrocarbons found in nature. The primary constituent is methane, but the composition varies widely. The hydrocarbon constituents may be entirely methane or, as

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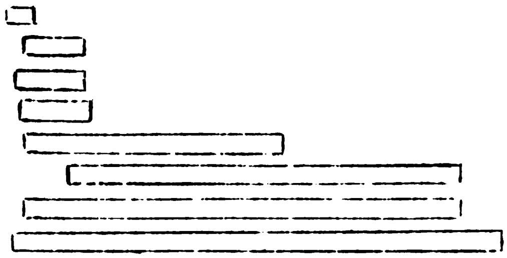
is usual, methane and ethane with traces of propane and butane. Frequently natural gas contains some of the higher hydrocarbons such as pentane, hexane, and heptane. Nitrogen is usually present and occasionally carbon dioxide. Natural gas may contain helium as it is the source of helium used in dirigibles. Moreover gas from certain regions may contain exceedingly dangerous quantities of hydrogen sulphide.

Explosive percentages of natural gas occasionally occur in mine air owing to cutting into old drill holes or leaks from gas or oil wells extending through the coal beds.

Acetylene

Acetylene is not a normal constituent of mine air but may occur in it owing to the presence of extinguished carbide lamps or the spilling of calcium carbide in moist or wet places. A pound of carbide will produce slightly less than 5 cubic feet of acetylene, and approximately 200 cubic feet of air would be necessary to dilute this quantity of gas to a nonexplosive mixture.

Explosive Limits of Mixtures of Combustible Gases With Air[1]

GAS	Gas mixture in air, percent		
	Lower	Upper	0 20 40 60 80
Gasoline vapor	1.4	6.0	
Natural gas[2]	4.8	13.5	
Ethane	3.2	12.5	
Methane	5.0	15.0	
Hydrogen sulphide	4.3	46	
Carbon monoxide	12.5	74	
Hydrogen	4.1	74	
Acetylene	2.3	80	

[1] By explosive limits are meant the maximum and minimum percentages of a combustible gas in air between which propagation of flame takes place through the mixture when ignited.

[2] 83.5 methane and 16.5 ethane by combustion analysis.

NOTE. - In explosions of methane and air the flame travels fastest in mixtures containing 9.5 to 10 percent of methane (at the rate of about 23 feet per second). The maximum pressure developed by an explosion is about 115 pounds per square inch.

Complete Combustion Reactions With Oxygen

Methane	$CH_4 + 2\ O_2 = CO_2 + 2H_2O$
Ethane	$C_2H_6 + 3.5\ O_2 = 2\ CO_2 + 3\ H_2O$
Hydrogen	$2\ H_2 + O_2 = 2\ H_2O$
Carbon monoxide	$2\ CO + O_2 = 2\ CO_2$
Acetylene	$C_2H_2 + 2.5\ O_2 = 2\ CO_2 + H_2O$

Gasoline Vapor

Gasoline vapor is highly explosive and can cause both explosion and fire if crude oil escapes into a mine or gasoline is spilled in an enclosed or inadequately ventilated place. Petroleum vapors similar to gasoline or kerosene occasionally are present in coal mines owing to oil seepage through strata underlying or overlying the coal bed.

Sulphur Dioxide

Sulphur dioxide is not a normal constituent of mine air but is formed at times by the combustion of the sulphur in coal or ore during mine fires and explosions or in heating gobs and dumps. It is also produced under some circumstances by the use of explosives in blasting certain types of ores, such as those containing high percentages of sulphur or sulphides, and large quantities are produced in refining these ores; traces may come from the explosive itself. Moreover, some mines containing deposits of native sulphur have considerable quantities of this gas.

Hydrogen Sulphide

Hydrogen sulphide ("stink" damp) sometimes occurs in coal mines in "gobs" or dissolved in pools of stagnant water or is released from water coming into mines through the strata, but the quantities are usually insignificant. Its common sources in significant quantities are the combustion of black blasting powder; blasting of sulphide ores; and dewatering of flooded areas of mines. Harmful quantities are often found in gypsum mines, in the digging of tunnels, caissons, and shafts, and in natural gas. Explosive quantities of hydrogen sulphide have not been found in mines so far as can be ascertained.

Oxides of Nitrogen

Oxides of nitrogen are sometimes found in the products of combustion of explosives, especially when blasting is done with certain types of explosives in wet places.

PHYSIOLOGICAL EFFECTS OF MINE GASES

Air and Oxygen

Man has become accustomed to an atmosphere that contains approximately 21 percent oxygen at an atmospheric pressure corresponding to ordinary altitudes. Any deviations from these values tend to produce abnormal conditions, and the greater the deviation the greater the abnormality, also the greater the probability of harm to the health of persons breathing the air or living in it.

A decrease in the oxygen concentration is by far the most significant gas condition in mines. Any atmosphere containing less than 16 percent of oxygen should be considered dangerous. The severity of the effects increases as the concentration of oxygen decreases. As activity increases oxygen consumption, strenuous work tends to exaggerate the effects of oxygen want.

A decrease in pressure below atmospheric also has an adverse effect on health similar to a decrease in the oxygen content of the air. This is evidenced by the symptoms encountered in mountain climbing.

High concentrations of oxygen may also have adverse effects. Pure oxygen causes irritation and inflammation of the respiratory tract if breathed continuously for a prolonged period. The adverse effects of pure oxygen are greatly increased by an increase in pressure.

Air under several atmospheres of pressure also has adverse effects on health, owing principally to the fact that when the pressure is suddenly decreased nitrogen, which has been dissolved in the blood because of the increased pressure, is released. The transportation of the gas bubbles of nitrogen in the blood produces the symptoms known as caisson illness or "the bends."

The oxygen content of air breathed by man is very important in (1) normal mine ventilation; (2) encountering stagnant air as in old mine workings, atmospheres produced by mine explosions and mine fires, and the use of respiratory protective devices; (3) administration of oxygen in the treatment of gas poisoning; and (4) working in compressed air.

Carbon Dioxide

Carbon dioxide is a respiratory stimulant. It is therefore physiologically active and cannot be classed with the physiologically inert gases, although it is not highly toxic. One-half percent of carbon dioxide causes only a slight, unnoticeable increase in lung ventilation. A concentration of about 3.5 percent is necessary before one is definitely conscious of increased respiratory effort. Data indicate that one can continue to work for a protracted period at a concentration of 5 percent; however, most persons would probably be incapacitated by concentrations above 6 percent. Symptoms of slight poisoning are depression, headache, chilliness, and fatigue. Subnormal body temperatures are encountered. More pronounced symptoms are shortness of breath, difficult or painful breathing, severe panting, dizziness, nausea, and unconsciousness. High temperatures (80° F. or more) are likely to accentuate the harmful effects of carbon dioxide.

Carbon Monoxide

Oxygen is absorbed in the lungs by the hemoglobin in the blood to form oxyhemoglobin. The oxygen is carried in this manner to the tissues where it is used to support the vital functions. The process is continuous. The hemoglobin that has given up its oxygen returns to the lungs for a new supply. Carbon monoxide reacts approximately three hundred times as readily with hemoglobin as does oxygen, and the carbon monoxide hemoglobin formed is more stable than oxyhemoglobin.

Hemoglobin combined with carbon monoxide is not available for carrying oxygen; if considerable hemoglobin is combined with carbon monoxide the tissues are inadequately supplied with oxygen and as a result become impaired so that weakness and collapse ensue. When 60 to 80 percent of the hemoglobin becomes incapacitated by union with carbon monoxide or otherwise, insufficient oxygen is transported to the tissues to maintain life.

Concentrations of carbon monoxide up to 0.04 percent by volume when breathed for a period of 1 hour produce virtually no symptoms. Concentrations ranging from 0.04 to 0.08 percent cause more definite symptoms such as headache, dizziness, and nausea. Concentrations ranging from 0.08 to 0.12 percent cause severe symptoms but are not necessarily dangerous for 1 hour of exposure. Concentrations ranging from 0.12 to 0.16 percent when breathed for 1 hour may produce collapse and are therefore dangerous. Concentrations above 0.16 percent become increasingly dangerous as the concentration increases, and a concentration of 0.5 percent may produce unconsciousness in a few minutes.

If a victim of carbon monoxide poisoning is brought into air free from carbon monoxide, the carbon monoxide hemoglobin breaks down and the carbon monoxide is eliminated from the blood provided the hemoglobin is not too heavily concentrated with carbon monoxide. The administration of pure oxygen increases the rate of elimination of carbon monoxide several times, and the administration of a mixture of carbon dioxide and oxygen further increases the rate of elimination. (See figure 1 and description of resuscitation.)

Nitrogen, Methane, and Hydrogen

Nitrogen, methane, and hydrogen are physiologically inert. They have no deleterious effect on man except when present in amounts that will dilute the air until the oxygen is inadequate to meet the demands of the body (see Air and Oxygen). As the ratio of oxygen to nitrogen in normal air is 1:4, it requires approximately 5 percent of excess diluents to reduce the oxygen content 1 percent; however, high nitrogen or high methane air with their resultant decrease in oxygen have caused many deaths in mines.

Hydrogen Sulphide, Oxides of Nitrogen, and Sulphur Dioxide

Hydrogen sulphide, oxides of nitrogen, and sulphur dioxide are all very poisonous and even in small proportions are harmful to man.

The compounds differ, however, in their physiological action. Hydrogen sulphide in high concentrations causes death by paralyzing the respiratory center. Moderately high concentrations cause cessation of respiration owing to overstimulation of the respiratory center, and low concentrations are mainly irritating because they cause conjunctivitis or inflammation of portions of the eyes or eyelids.

Oxides of nitrogen produce edema (swelling due to effusion of watery liquid into tissues) of the lungs, and the effects may be delayed 24 to 48 hours.

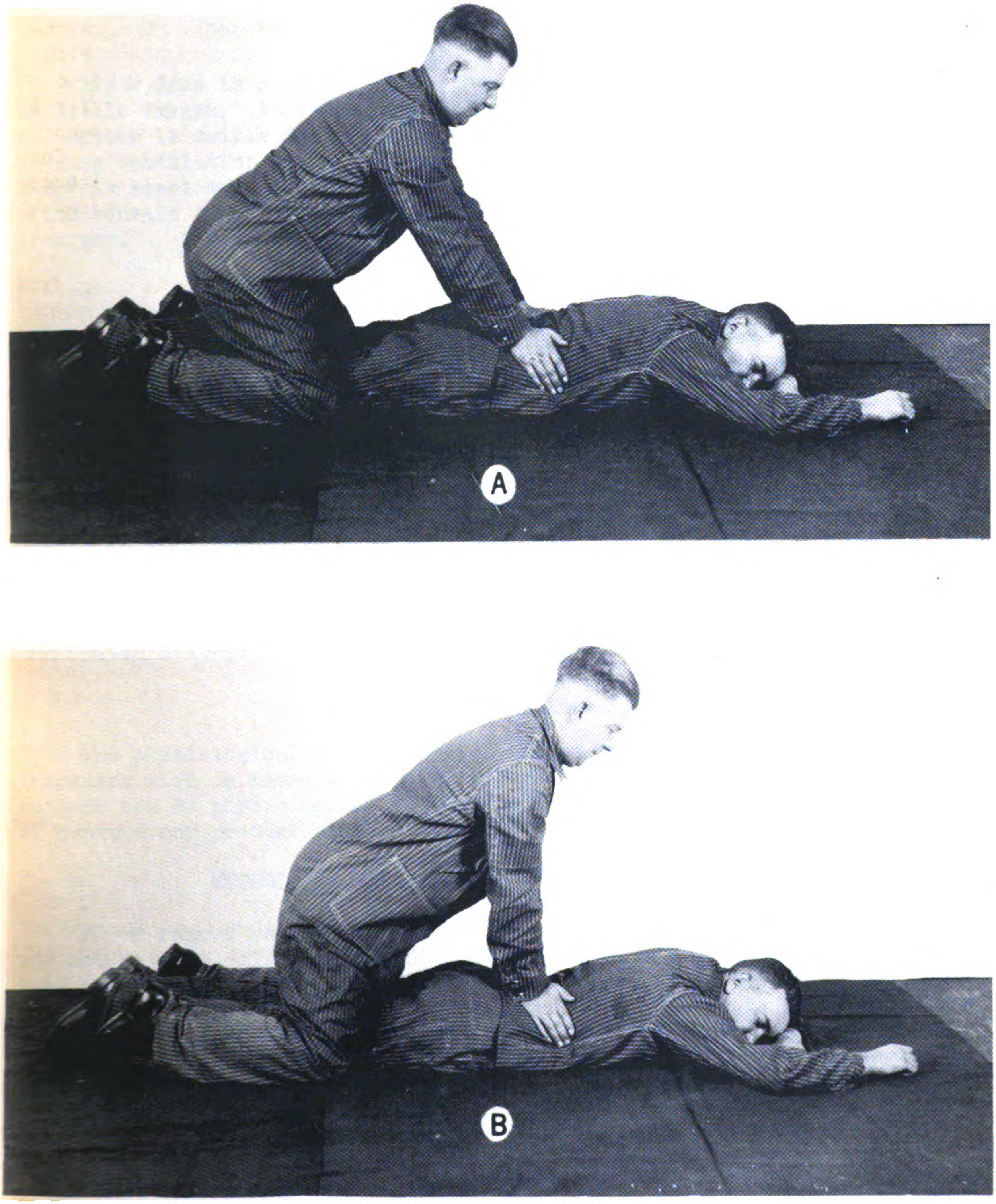


Figure 1.- Artificial respiration, prone pressure method: A, Inspiration; B, expiration.

The main effect of low concentrations of sulphur dioxide is irritation of the nasal and other respiratory passages; high concentrations, however, are dangerous.

Black Damp

Black damp is a mixture of carbon dioxide and nitrogen with relatively little oxygen. As it is made up primarily of nitrogen, its physiological action is mainly that of an inert gas with possibly some slight increase in lung ventilation due to the carbon dioxide. Popularly the term "black damp" is sometimes applied to gases found after mine fires or explosions which contain small percentages of carbon monoxide. The term is disappearing from use.

Fire Damp

Fire damp is essentially methane, hence its physiological action is the same as that of methane or an inert gas. The term is usually applied to an explosive mixture of methane and air.

After Damp

After damp is a term applied to gases found after an explosion or fire with the inference that carbon monoxide is present in relatively large percentages; since it contains carbon monoxide, its physiological action will depend primarily upon the concentration of carbon monoxide present, although if enough inert gases are present a condition of oxygen want may also prevail. The term "after damp" is also disappearing from use, especially in the United States.

Hydrocarbon Vapors

The physiological activity of saturated compounds of the paraffin series increases with an increase in the number of carbon atoms, so that although methane has no physiological action concentrations of 0.1 percent by volume of heptane may produce a slight vertigo after about 5 minutes.

METHOD FOR REVIVING A PERSON OVERCOME BY GAS

First remove patient to fresh air. Then lay the patient on his belly, one arm extended directly ahead, the other arm bent at the elbow, and the face turned outward and resting on hand or forearm, so that the nose and mouth are free for breathing. Kneel, straddling the patient's thighs, with knees at such a distance from the hip bones as will allow placing the palms of the hands on the small of the patient's back with fingers resting on his ribs, the little finger just touching the lowest rib, the thumb and fingers in a natural position, and the tips of the fingers just out of sight. (See fig. 1A.)

With arms held straight, swing forward slowly, so that the weight of body is gradually brought to bear upon the patient. The shoulder should be directly over the "heel" of the hand at the end of the forward swing. (See fig. 1B.) Do not bend elbows. This operation should take about 2 seconds. Now, swing backward immediately so as to remove the pressure completely. After 2 seconds swing forward again. Repeat deliberately 12 to 15 times a minute the double movement of compression and release - a complete respiration in 4 or 5 seconds.

Continue artificial respiration without interruption until natural breathing is restored; if necessary, 4 hours or longer, or until a physician declares the patient is dead.

As soon as artificial respiration has been started and while it is being continued, an assistant should loosen any tight clothing about the patient's neck, chest, or waist. Keep the patient warm. Do not give any liquids whatever by mouth until the patient is fully conscious.

To avoid strain on the heart when the patient revives, he should be kept lying down and not allowed to stand or sit up. If the doctor has not arrived by the time the patient has revived, he should be given some stimulant, such as one teaspoonful of aromatic spirits of ammonia in a small glass of water or a hot drink of coffee or tea.

DETECTION OF MINE GASES - SAMPLING AND ANALYSIS

The essentials in examining mine gases are: (1) Select a place of sampling that will be most representative of the atmosphere in question, being guided by such factors as density of gas, nearness to source of gas, air movement, and purpose of test; (2) be sure the gas entering the detector or sample tube is the gas in question; (3) use a method of detection or analysis that will give reliable results within the desired range of accuracy.

Sampling and Analysis of Mine Gases

A "complete" analysis of normal mine air (from ventilated workings) as performed by the Bureau of Mines usually comprises determination of the quantity of carbon dioxide, oxygen, methane, and nitrogen in the air. Where it is suspected that the air is contaminated by leaks from fires or fire seals, products of detonation of explosives, exhaust gases from gasoline engines, etc., the laboratory should also be requested to make an examination for carbon monoxide and hydrogen. "Complete" analysis of a mine-fire sample of gas comprises determination of carbon dioxide, oxygen, carbon monoxide, methane, nitrogen and, in some cases, hydrogen content.

Collection of Mine Gas Samples

The essentials in collecting a sample of gas are: (1) Use a sample container and method of filling that will not allow leaks or alteration of the sample between the time of sampling and the time of analysis; (2) be sure the sample container is filled with the gas before closing; (3) be sure to close the container tightly; (4) make written notes regarding the type of sample, location, date and hour of sampling, temperature and relative humidity,

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velocity or quantity (or both) of air or pressure on the seal (if it is a sample from a sealed area), and such other data as may be necessary for interpreting the analysis. Submit a duplicate copy of these notes to the laboratory where the analysis is to be made. The collector should always advise the laboratory if, in his opinion, the sample contains an explosive mixture of gas; this is important.

Sampling Procedure

Vacuum sampling tubes are filled by breaking the tapered glass tip at the mark scratched on it. After the gas rushes into the tube the capillary stem is closed by forcing over it a metal cap that contains a soft, adhesive wax. Gases may be collected from behind seals in a container of this type by using a rubber hose connected to a pipe or tube that extends through the seal into the sealed region. The diameter of the hose should be slightly larger than the glass tip of the sampling tube. First purge the hose with gas from behind the seal, then insert the sampling tube into the free end of the hose until the shoulder of the tube fits tightly into the hose. Break the tapered tip by bending the hose.

In sampling by water displacement the sample container is filled with water and emptied at the place of sampling. The carbon dioxide content of the sample will decrease slightly owing to the solubility of this gas in the water which adheres to the inside surfaces of the container.

In sampling by air displacement the gas is pumped through the container until the original content of gas has been displaced by the sample; a quantity of gas 15 to 25 times the volume of the container should be pumped through.

Types of Sample Containers

The glass vacuum-tube container is satisfactory for mine work and is recommended for samples to be shipped or stored before analysis. Samples to be analyzed within a few hours after sampling may be collected in copper, brass, or aluminum containers with metal cocks or glass containers having glass cocks, or they may be closed by rubber-hose connections and screw clamps. Iron or tinned-iron containers should not be used as the oxygen of the sample may combine chemically with the iron. Citrate bottles may be used; the rubber gasket should be in good condition, and the snap fastener should close tightly. Fruit jars or ordinary bottles are not satisfactory and should not be used unless other types of containers are not available.

Analysis of Gas Sample

The Haldane apparatus is designed to determine percentages of carbon dioxide, oxygen, methane, carbon monoxide, hydrogen, and nitrogen with an accuracy of 0.02 to 0.03 percent. It may be used when the quantity of combustible or explosive gases does not exceed the lower explosive limit and when there is sufficient oxygen in the original sample to burn completely the combustible gases. Such samples include most of those taken in investigations of ventilation, quality of air, and amount of methane liberated in various sections of a mine.

The Orsat apparatus is used to analyze samples that contain quantities of combustible gases within or above the explosive range or that contain insufficient oxygen to burn the combustible gases; these include explosive mixtures of methane, mine fire samples, exhaust gases from gasoline engines, natural gas, etc. With the type of Orsat apparatus used in laboratories the percentages of carbon dioxide, oxygen, carbon monoxide, hydrogen, methane, and nitrogen may be determined with an accuracy of 0.2 to 0.4 percent. The portable type is somewhat less accurate but is adequate for the purpose for which it is ordinarily used.

The pyrotannic apparatus is used in conjunction with both the Haldane and Orsat types for determining carbon monoxide in quantities below their lower limits of determination.

Oxygen

Determination of the oxygen content of mine air is important in ventilation studies to detect atmospheres that contain insufficient oxygen to support life and to determine the tightness of seals in fire areas and the progress of extinction of sealed mine fires.

The canary is not a safe detector for atmospheres deficient in oxygen as the canary can live in low-oxygen atmospheres that would be fatal to man.

A naphtha-fed flame safety lamp is extinguished by atmospheres that contain less than about 16 percent of oxygen, oil and candle flames by ones that contain less than 17 percent oxygen, and the carbide lamp by ones that contain less than 13 percent. Methane in mine air may cause slight variation in these figures.

Only the flame safety lamp should be used to detect oxygen deficiency in coal mines, sewers, or tunnels where explosive gases may be present; the flame safety lamp is not safe if the explosive gas is hydrogen or petroleum gases. Other devices may be used with safety only in nongassy locations; the carbide lamp is definitely hazardous for detecting oxygen deficiency, and scores of persons have been killed in oxygen-deficient atmospheres in both coal and metal mines while using carbide lamps.

In entering an atmosphere that may be deficient in oxygen and may contain explosive and poisonous gases such as methane and carbon monoxide, probably the best procedure is to be equipped with oxygen breathing apparatus and to carry a canary to indicate carbon monoxide and a flame safety lamp to indicate explosive gas and oxygen deficiency.

Carbon Monoxide

The determination of small quantities of carbon monoxide in mine air is of vital importance because of its poisonous effect on man and its significance in indicating the presence or condition of mine fires.

Canary Birds

The canary if carefully observed for signs of distress serves as an indication of a dangerous atmosphere. The average canary exposed to 0.20 to 0.25 percent of carbon monoxide will show distress in 2 to 3 minutes, whereas a man will experience symptoms of headache and dizziness in about 10 minutes. The canary is not a satisfactory detector for carbon monoxide in concentrations of 0.10 percent or less, moreover the canary can live in atmospheres so deficient in oxygen that a man would succumb. Hence, it is extremely hazardous to depend on warning from the canary in an atmosphere that may be deficient in oxygen.

Hoolamite Detector

Portable apparatus for detecting quantities of carbon monoxide immediately dangerous to man has advantages (as well as some disadvantages) over the use of the canary. The advantages are: More rapid determination; lower limit of detection (0.07 to 0.10 percent); range of semiquantitative indication from this lower limit to 1 or 2 percent; large number of determinations possible; and use by men wearing oxygen breathing apparatus in atmospheres containing insufficient oxygen to support life. The main disadvantage of the detector as against the canary is that the canary's action is voluntary while a man may have a detector with him and fail to use it until he has breathed heavily of the atmosphere containing carbon monoxide. It may be used to confirm the presence, but not the absence, of carbon monoxide in air from behind fire seals.

Pyrotannic Apparatus

This apparatus is used to determine the carbon monoxide content of the blood; the apparatus can also be used to determine concentrations of carbon monoxide in air, which range from 0.01 to 0.20 percent but is safe only when used by a relatively skilled person and when the various parts of the apparatus are kept in good working order.

Sampling and Analysis

When judgment is used this is a reliable method for determining the carbon monoxide content of gases collected from behind fire seals or the carbon monoxide content in conjunction with that of other constituents such as carbon dioxide, oxygen, methane, and nitrogen.

A flame safety lamp cannot be used to detect carbon monoxide in mines; the quantity detectable by this means would be fatal to a man before he could complete the test, unless he were also wearing oxygen-breathing apparatus.

Methane and Explosive Gases

The choice of methods for examining mine air for methane or other combustible gases depends largely on the purpose of the examination and the accuracy desired.

Flame Safety Lamp

Dangerous quantities of methane are shown by the formation of a characteristic blue cone or cap on the flame of a safety lamp. The range of detection for the average observer is 1 to 4 percent, as shown in figure 2. At about 5 percent (lower explosive limit of methane) the flame will be extinguished by a small explosion within the lamp. The flame safety lamp is not accurate enough for the determination of methane content in the return air of splits or in the main return unless a dangerous quantity of methane is present.

Indicators and Detectors

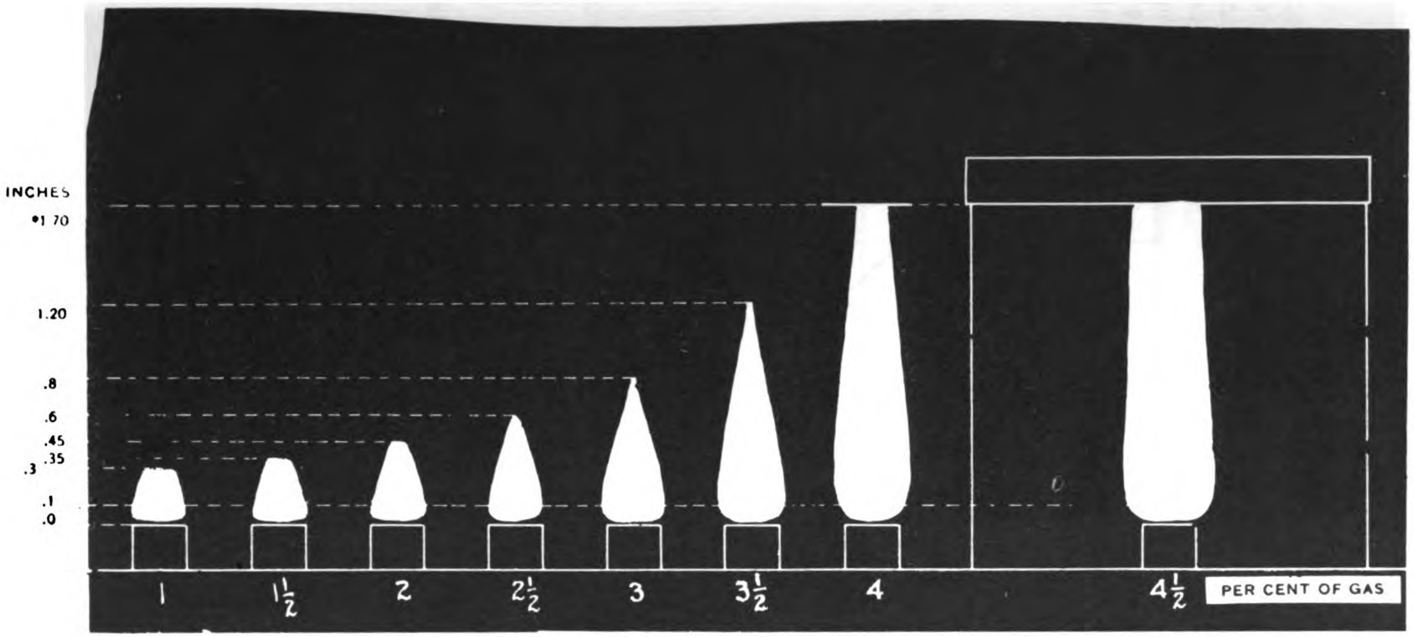
The Burrell methane indicator, the Martiessen methane detector, and the U. C. C. (Union Carbide Co.) and the M. S. A. (Mine Safety Appliances Co.) indicating methane detectors are portable methane indicators or detectors approved for use in gassy mines.

Sampling and Analysis

This is the most reliable method for determining methane content, but from a practical standpoint it is not suitable for the routine inspection of working places. (See Sampling and Analysis of Mine Gases.)

Other explosive gases besides methane may be detected by the devices mentioned.

The curves in figure 3 show the changes in oxygen, methane, carbon monoxide, and carbon dioxide content of the gas behind a fire seal on successive days after sealing. The condition of the fire at various periods may be interpreted from the curves as follows: (A) The oxygen dropped below 12 percent before the methane reached 5 percent which eliminated the possibility of an explosion. (B) If the methane had increased rapidly as represented by the dotted line an explosion probably would have occurred. (C) The increase in oxygen and the decrease in methane show dilution with air caused by a leaking seal, negative pressure on the seal which makes it difficult to obtain a sample of the gas that is not contaminated with air, or a leak in the gas-sample container. This condition should be investigated immediately to prevent the formation of an explosive mixture behind the seal. (D) The carbon monoxide has disappeared, which indicates that the fire is extinguished but the area still may be in a heated condition. Do not open fire seals and ventilate without the assistance and advice of persons experienced with fires in gassy mines. (E) The methane often increases to as much as 75 to 90 percent.



* Upper limit of visible gas cap.

Figure 2.- Height of gas cap with naphtha-fed flame safety lamp. Testing flame 1/10 inch high. Total height of cap indeterminate. This figure does not depict any particular type of lamp. The height of cap obtained with a given percentage of methane will vary somewhat depending on the type of lamp, type of fuel, and oxygen content of the atmosphere; and the condition of the eyes of the observer will have a definite effect on the accuracy of interpretation of the height of gas cap observed.

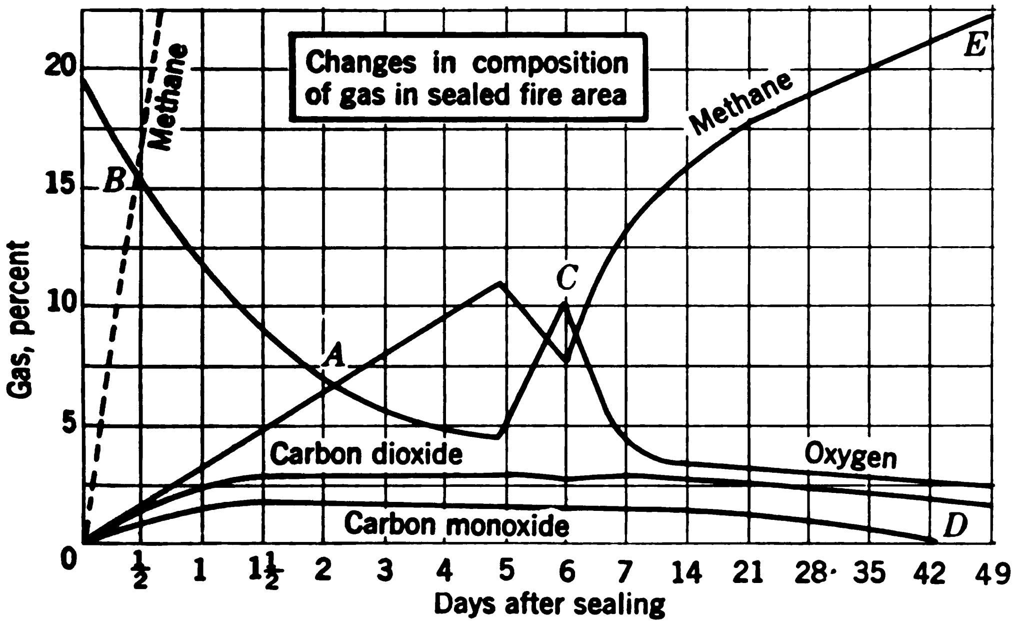


Figure 3.- Change in composition of gas behind seals after sealing a fire in a gassy coal mine.

Hydrogen Sulphide, Sulphur Dioxide, and Oxides of Nitrogen

Hydrogen sulphide, sulphur dioxide, and oxides of nitrogen are detected by their characteristic odors and irritating effects. The odors become less as exposure continues and do not give reliable indication of the danger. The canary is not satisfactory for detecting dangerous concentrations of these gases. Hydrogen sulphide may be detected by darkening of a paper moistened with lead acetate solution. Small percentages of hydrogen sulphide may be determined by the hydrogen sulphide detector; air is passed through a glass tube containing a material which darkens when exposed to hydrogen sulphide, and the percentage of hydrogen sulphide is determined by measuring the length of coloration in the tube. Hydrogen sulphide, sulphur dioxide, and oxides of nitrogen may be determined by sampling and analysis. These gases are highly reactive chemically, and the ordinary mine-air vacuum sampling tubes are not suitable for collecting samples containing them as they react with particles of dust and moisture in the tubes and are likely to be lost from the sample before the analysis can be made. The most satisfactory procedure is to make these determinations without delay at the place of sampling with special analytical equipment.

CONCLUSION

Those engaged in the operation of noncoal as well as coal mines should familiarize themselves with matters connected with gases that may be found in mines. Asphyxiating gas conditions can occur in any type of mine, and under some conditions explosive gases may be found not only in gassy and so-called nongassy coal mines but also in metal or other noncoal mines. The well-informed mining man should be able to cope with gas situations even when they are abnormal. Asphyxiating gases in poorly ventilated coal and metal mines take a heavy toll of life every year; in one month (July 1937) at least five persons were killed by asphyxiating gases in three coal mines in three different States, yet these unfortunate occurrences could have been prevented by the use of available precautionary measures. Similarly, many persons have been made seriously ill and several have been killed relatively recently by poisonous gases from mine fires and explosions, and in almost all instances the dangers could have been avoided by the use of safety procedure that should be well known to mining people.